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Mesoscale interactions on wind energy potential in the northern Aegean region: a case study

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Abstract

Aegean coast and surrounding areas are promising higher wind power potential. In this study the reasons of the higher wind power potential in the region of the northern Aegean coast of Turkey and surrounding islands were discussed. The channel effect, route of cyclones and surface pressure gradients were evaluated over the region. Estimated results of the Weibull parameters illustrate the higher wind power potential in the region.

List of symbols

P_w wind energy density
V wind speed
$\bar{V}$ mean wind speed
ρ air density
c scale parameter
k shape parameter
σ standard deviation
$\bar{E}$ mean energy

1. Introduction

It is known that the wind is one of the most suitable and cost-effective alternative energy sources. Wind resource varies with time of day and season of year and even to some extent from year to year. It is also sensitive to variations with topography and weather patterns.

The rapid growth of interest in wind energy has been created during the past 25 years. In literature, it is expected that the greatest wind potential exist in North America, Ukraine, Australia and some parts of Europe. Wind sources in Europe are

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explained in the European Community wind atlas. Denmark, the Netherlands, the north of Gibraltar, South France, United Kingdom, Ireland, Scotland, and Greece are promising regions [1]. Additionally, with plenty of windy sites not only along the coast but also in its mountain regions, Spain has also been promising in Europe. The Spanish government had planned to increase the wind power capacity to 175 MW by the year 2000 [2].

More than 15,000 wind turbines in U.S.A. and 2800 in Denmark have been integrated into existing utility system [3]. Recently, the cost of wind-generated electricity has also gradually decreased. Consequently, there is gradually interest for the wind energy systems in the world.

Wind energy programs have been reviewed for the Mediterranean countries. Recent papers presented the picture of wind power potential along the coast of Greece and the islands and western coast of Turkey [4–6]. Lalas et al. [5], evaluated the wind energy potential for Aegean Sea and Greek islands in surrounding area. Tolun et al. [7] presented the first results of the Gökçeada island wind power potential. Şen [8] investigated the wind energy reliability by using Gökçeada island station data. İncecik and Erdoğmuş [6] also investigated wind power potential on the western coast of Anatolia. In that work, the stations in eight sites investigated the variability of wind power on the western coast of Asia Minor. Bozcaada, Gökçeada, Bodrum, Çanakkale and Ayvalık sites presented the higher potential. They found maximum scale parameters in the northern part of the region involving Gökçeada, Bozcaada islands and Çanakkale sites. Bozcaada that is one of the islands of northern area of the coast has been defined as the best suited for the application of wind energy among all the stations. This behavior has been attributed to the meso-scale circulation in the area and local channeling effect between the islands and the mainland in the region.

This paper attempts to explain the reasons of the higher wind power potential at the northern Aegean region. With this purpose, winter and summer weather patterns and meso-scale circulations over the Eastern Mediterranean and Aegean Sea were identified. Additionally, surface pressure gradients that indicate the intensity of surface wind speeds in the region were investigated.

2. Observations and analysis

Figure 1 shows the western coast of Turkey and investigation region. According to Biel [9] and Baum and Smith [10], pressure distribution over the Mediterranean in winter, is controlled by three factors: the Eurasiatic high-pressure axis, the subtropical high and its extension over North Africa, and the belt of low pressure over the extremely warm Mediterranean sea itself. In summer, a high-pressure system covers the eastern Mediterranean and Balkan area up to the Black Sea. A thermal low over the Anatolian Plateau is evident during day-hours because of heating of the dry land. The balance between these two systems defines the weather conditions over the Aegean Sea. When the high-pressure system is strengthened it extends in an easterly direction and the pressure gradient across the Aegean is weakened. The synoptic circulation is weak from the north. Therefore, local circulations as like as sea and land breezes

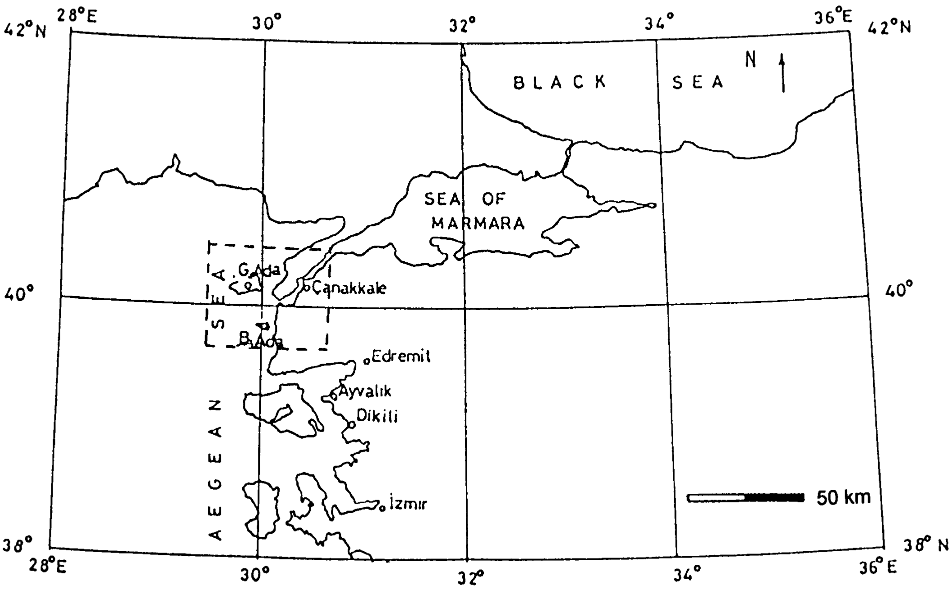

Fig. 1. A map of Aegean coasts of Turkey (dashed lines indicate the region).

develop over the region. When the high-pressure system weakens, the pressure gradient over the Aegean becomes stronger. The northerly winds are dominant over the Aegean in this period. This kind of wind pattern is called Etesians [9]. Etesians control the Adriatic, Ionian and Aegean seas, Greece and to a certain extent Asia Minor. The Etesians over the Adriatic and Ionian seas are northwest winds; over the Aegean and Greece north winds; over Turkey northeast winds. In summer the Etesians are particularly pronounced on the western shore, with strong northeast winds in the Straight of Dardanelles (Çanakkale).

The pressure patterns described above represent average conditions. Knowledge of the most important storm tracks, particularly those of winter, when all the Mediterranean is controlled by eastbound disturbances, is of great help in understanding the distribution of prevailing winds in the region. Alpert et al. [11] calculated and analyzed monthly cyclone tracks in the Mediterranean. Besides, they made climatological analysis of Mediterranean cyclones [12]. They showed the day-to-night variation along with annual variation in the number of cyclones and they explained at the eastern Mediterranean positive thermal effects that are much more pronounced than at the western Mediterranean. Alpert et al. [11] showed that there is a significant route of winter cyclones leaving through the Aegean Sea and passing over the studied region towards the Black Sea.

Aegean region generally records north and northeast winds in both winter and summer seasons. Furthermore, wind characteristics vary in the case of islands and mainland composition. This kind of effect is known channel effect. There are many examples on channel effects in the Mediterranean. They are pronounced in channels

between islands or between islands and mainland. Channel effect over the Dardanelles that is the old name of Çanakkale is well illustrated in the summer by historical records. Its velocities at 1 and 1.5 km over Gallipoli (Gelibolu) that is on the European side of Çanakkale are 3.6 m s^{-1} surface winds on the direction of NE and 6.2 m s^{-1} at over the boundary layer on the direction of NNE [9]. Figure 1 also illustrates the position of estimated channel effect over straight of Çanakkale. As seen in Fig. 1, Bozcaada Island may be exposed to the channel effect over the straight of Çanakkale.

In addition to the surface pressure pattern characteristics in synoptic scale, it is important to investigate the surface pressure gradients to obtain an indicator for wind energy potential. In this work, surface pressure gradients involving the northern Aegean region are classified and interpreted. A classification of the strength of the surface pressure gradients has been made with a similar method of Kallos et al. [13] and Helmis et al. [14] by using mean sea level pressure maps [15] for selected winter and summer cases (Table 1).

The hourly wind speed data of 1995–1996 selected winter and summer months were analyzed for predicting the energy output in the region of Gökçeada, Bozcaada islands and Çanakkale site which are indicated in earlier studies [6, 7] as higher wind power potential regions. Table 2 presents the information of the period and the characteristics of the data.

In literature, wind energy density P_w, is given by the time rate of change of wind speed per unit area.

$$P_w = \rho V^3/2 \tag{1}$$

where V is the wind speed (m s^{-1}) and ρ is the air density (kg m^{-3}). Weibull distribution has been used most often in atmospheric sciences to model variations in wind speeds [16]. The form of the Weibull distribution is controlled by shape and scale parameters. It is widely used in describing wind speed data and is expressed as two-parameter function of the form:

$$P(V) = (k/c)(V/c)^{k-1}\exp[-(V/c)^k] \tag{2}$$

where c is a scale parameter (m s^{-1}) and k a dimensionless shape parameter and $k > 0$, $c > 0$.

The Weibull parameters can be estimated from the mean wind speed and Γ function as follows Burington and May [17], Justus et al. [18], Justus [19], and Wilks [16]:

$$\bar{V} = c\Gamma(1+1/k)$$

and

$$\sigma/\bar{V} = [\Gamma(1+2/k)/\Gamma^2(1+1/k)-1]^{0.5}$$

In accordance with above statistics the mean energy assuming an average air density of 1.23 kg m^{-3} is given as:

$$\bar{E} = 0.615\overline{V^3}$$

where

Table 1
Classification of the strength of the surface pressure gradients for the selected winter and summer periods according to the observed pressure gradients in the area of northern Aegean Sea. A—very weak pressure gradients ($\partial p/\partial n < 0.5$ mb/100 km); B—relatively weak pressure gradients (0.5 mb/100 km $< \partial p/\partial n <$ 1.0 mb/100 km); C—relatively strong pressure gradients (1.0 mb/100 km $< \partial p/\partial n <$ 5.0 mb/100 km) and D—strong pressure gradients ($\partial p/\partial n >$ 5.0 mb/100 km)

Day	Surface pressure gradients					
	July 95	August 95	December 95	January 96	July 96	August 96
1	A	B	C	C	A	A
2	C	A	C	C	A	A
3	C	C	C	C	A	C
4	B	B	C	C	C	C
5	A	B	C	C	B	C
6	B	B	C	C	C	C
7	B	C	C	B	C	C
8	C	C	C	A	C	B
9	C	B	C	C	B	B
10	C	C	C	A	C	C
11	C	C	C	C	C	C
12	B	C	C	B	C	C
13	B	C	B	A	C	C
14	C	C	C	C	C	C
15	B	A	A	C	C	C
16	A	B	B	C	C	A
17	C	B	C	C	C	B
18	C	B	C	C	C	B
19	C	C	C	B	C	C
20	C	C	C	A	C	B
21	C	A	A	B	C	B
22	C	A	C	B	C	A
23	C	C	A	C	C	C
24	C	C	C	A	C	B
25	C	A	C	C	B	B
26	C	C	C	A	A	A
27	C	B	C	C	C	C
28	C	A	C	A	C	C
29	C	C	A	A	C	C
30	C	C	D	B	C	C
31	C	C	C	D	A	B

$$\overline{V^3} = c^3\Gamma(1+3/k)$$

and Γ is the gamma function. The estimated results of the Weibull parameters and mean energy at 30 m in the region for selected periods are given in Table 3.

The mean energy values are estimated at Bozcaada, Çanakkale and Gökçeada locations for 30 m that is considered hub height. The calculations in Table 3 were adjusted by using power law [20]. Power law exponent has been selected as 0.2 for

Table 2
Meteorological stations and the site information

Station	Instrument	Height of obs. (m)	Data
Bozcaada	Three-cup anemometer	10.0	July–Aug. Dec. 1995–Jan. July–Aug. 1996
Çanakkale	Three-cup anemometer	10.0	July–Aug. Dec. 1995–Jan. July–Aug. 1996
Gökçeada	Three-cup anemometer	7.45	July–Aug. Dec. 1995–Jan. July 1996

Table 3
The results of scale (m s^{-1}) and shape (dimensionless) parameters, EPF (dimensionless) and mean energy (W m^{-2}) values at 30 m in the region

Site	Month	$\bar{V}$ (m s^{-1})	k	c (m s^{-1})	EPF	$\bar{E}$ (W m^{-2})
Bozcaada	July 1995	8.3	2.83	6.91	1.45	505.6
$\varphi = 39° 48' $ N	Aug. 1995	7.3	2.26	5.72	1.66	394.1
$\lambda = 26° 02'$ E	Dec. 1995	9.7	1.58	6.63	2.53	1410.9
	Jan. 1996	9.2	2.31	7.26	1.69	803.3
	July 1996	7.6	2.40	6.04	1.57	421.3
	Aug. 1996	7.2	2.22	5.61	1.68	381.7
Çanakkale	July 1995	5.4	2.35	4.26	1.65	158.7
$\varphi = 40° 08'$ N	Aug. 1995	5.0	2.19	3.87	1.73	131.8
$\lambda = 26° 24'$ E	Dec. 1995	7.2	1.43	4.66	3.03	689.6
	Jan. 1996	5.8	2.21	4.52	1.75	208.7
	July 1996	5.8	2.39	4.61	1.57	186.9
	Aug. 1996	4.8	2.11	3.69	1.79	120.5
Gökçeada	July 1995	5.2	1.90	3.83	1.97	168.6
$\varphi = 40° 11'$ N	Aug. 1995	4.6	1.83	3.34	2.02	120.2
$\lambda = 25° 54'$ E	Dec. 1995	7.6	1.79	5.48	2.05	549.6
	Jan. 1996	8.4	1.85	6.14	2.08	751.9
	July 1996	5.3	1.63	3.68	2.33	211.7

daytime and 0.5 night-time respectively. Energy pattern factor (EPF) is defined $\overline{V^3}/\bar{V}^3$ [19].

3. Results and concluding remarks

The conditions for wind power should be evaluated under characteristics of the pressure gradients in the area. Promising regions for wind power potential can be selected by these considerations. The pressure gradients are classified as very weak,

relatively weak, relatively strong and strong based on the criteria stated in the caption of Table 1. Summarizing the findings, the pressure gradients were very weak 19% of the time, relatively weak 13% of the time, relatively strong 65% of the time and strong 3% of the time during the winter months. The corresponding values were very weak 15%, relatively weak 22% and relatively strong 63% during the summer months. The results of the surface pressure gradient characteristics showed similar trends for the winter and summer seasons in the region of interest. Observed gradients in the study area give mostly relatively strong values which vary between 1.0–5.0 mb per 100 km. There are relatively strong surface gradients which occurred 65% of the time during the winter period and 63% of the time during the summer period.

The shape parameter values k, are greater than 2 as denoted in Table 3. This is in agreement with the results of Lyons [21], İncecik and Erdoğmuş [6]. The higher shape parameters in the region in summer months can be explained by Etesians that are strong northeast winds along Aegean coasts as explained above. Lower shape parameters in winter months indicate the wind characteristics in the region that is affected by synoptic weather systems.

Energy pattern factor values vary between 1.45 and 3.03 depending on k. Shape parameter in the region in agreement with Justus's [19] results. Justus [19] indicate that it generally ranges between about 1.5 and 3.0 and average of close to 2.0.

The mean wind energy values found in the range of 120.5 and 1410.9 W m^{-2} in the region for 30 m hub height by using the two recent contrast seasons data. The mean energy values of Bozcaada that has maximum wind power potential for 30 m hub height, are 425.7 W m^{-2} in summer and 1109.1 W m^{-2} in winter respectively. Çanakkale site ranges between 149.5 W m^{-2} in summer and 449.2 W m^{-2} in winter; Gökçeada ranges between 166.9 W m^{-2} in summer and 657.7 W m^{-2} in winter respectively. Estimated parameters and mean energy values support the results of Lalas et al. [5] and İncecik and Erdoğmuş [6] in accordance with the northern parts of Aegean region.

Summarizing, the Aegean coasts of Turkey and its northern parts involving two islands are generally seen promising of higher wind speeds for wind power potential. Several reasons may be attributed to the higher wind power potential in the region. The relatively strong surface pressure gradients found in the northern Aegean coasts of Turkey support the higher wind power potential in the region of Bozcaada, Gökçeada islands and Çanakkale site.

Significant route of winter cyclones passing over the region towards the Black Sea and Etesians in summer and the channel effect over the straight of Çanakkale are other possible reasons.

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